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Performance of Apple Cultivars in the 1995 NE-183 Regional Project Planting: II. Fruit Quality Characteristics

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Abstract

The fruit quality performance of 19 apple (*Malus xdomestica* Borkh.) cultivars on Malling.9 (M.9) rootstock was evaluated for four growing seasons at 13 locations across North America as part of the NE-183 Regional Project, "Multidisciplinary Evaluation of New Apple Cultivars." At each site, trees were planted in 1995 in five randomized blocks with single-tree plots. Orchard management followed regional commercial recommendations for apple culture. 'Fortune' produced the largest fruit followed closely by 'Shizuka' and 'Enterprise'. 'Pristine' were the smallest fruit. Fruit shape of six cultivars was characterized as conic based on length/diameter (L/D) ratio. Three cultivars, 'Gala Supreme', 'NY 75414-1', and 'Pristine', were best described as oblate based on L/D ratio. At harvest 'Braeburn' and 'GoldRush' had the highest flesh firmness. 'Pristine' and 'Sunrise', both summer cultivars, had the lowest flesh firmness and soluble solids concentration (SSC). 'Gala Supreme' and 'GoldRush' had the highest SSC and 'GoldRush' and 'Pristine' produced fruit with the highest titratable acidity (TA) levels. Among red skin cultivars, 'Enterprise' and 'NY 75414-1' stood out with more than 85 % surface red overcolor. 'Suncrisp' had about 28% of the fruit surface covered with a reddish blush, which was significantly more than the other yellow skin cultivars. 'Arlet' and 'Gala Supreme' rated highest in skin surface russet formation. A stability analysis was performed for all variables measured. No cultivar proved perfectly stable, but 'Enterprise' and 'Ginger Gold' were stable for seven of nine variables. In contrast, 'Honeycrisp', 'NY 75414-1' and 'Suncrisp' were consistently unstable cultivars in all variables measured.

Introduction

During the 20th Century the U.S. fresh apple market was dominated by traditional cultivars like 'Delicious', 'Golden Delicious', and 'McIntosh'. In the early 1980s a "new" apple cultivar from Australia, 'Granny Smith', was introduced to U.S. growers and consumers. Production of this high quality apple quickly rose to rank fourth behind 'Delicious', 'Golden Delicious', and 'McIntosh'. Additional introductions soon followed, including 'Jonagold', 'Gala', 'Fuji' and later 'Braeburn'. Miller (27) identified several reasons for the heightened interest in new apple cultivars, including the desire to reduce the use of pesticides, the low rate of return for the traditional processing cultivars, consumer interest in a more diverse selection of high quality apples, and an expanded world market that had increased competition and consumer awareness. Additional factors contributing to the interest in new apple cultivars include a greater interest in local retail or specialty (niche) marketing, a drop in the premium prices received for cultivars introduced in the 1990's (29), a greater awareness of the health and dietary benefits associated with apples (9, 14, 22, 36), and a shift to meet more "extrinsic" (or value-added) consumer needs (29). Clearly, the pursuit of newer apple cultivars to meet grower needs and consumer preferences will continue (2, 3, 29).

The success of the newer apple cultivars has been due, in part, to their unique flavors and enhanced quality attributes (firmness, soluble solids, acidity, etc.) (17, 33). While appearance still ranks high in

[1]For location of authors, see Table 2.

consumer apple buying habits (1, 34), recent surveys and taste panels indicate that many consumers are selecting apples based on flavor and other internal quality attributes (21, 31). When asked why they buy apples, about 70% of U.S. consumers indicated that eating quality (flavor, taste, texture) was the reason for their purchase (21). Knowledge of apple quality characteristics most demanded by consumers can assist breeders in selecting new cultivars (20) and would aid growers in deciding which cultivars to plant.

Until recently, systematic evaluation of new apple cultivars was limited. Evaluations of performance of new cultivars and selections are often limited to those of the plant breeder at a few test sites or observations by growers and/or nursery personnel in the field. In 1994, Regional Project NE-183, titled "Multidisciplinary Evaluation of New Apple Cultivars", was initiated to systematically evaluate the performance of new apple cultivars in replicated trials under a wide range of climatic and edaphic conditions. Description and background information on the NE-183 Regional Project is provided by Greene (16). With respect to each fruit quality attribute, the two objectives of this paper are (1) to estimate and compare cultivar means across a wide array of environments, where each location-year combination was an environment, and (2) to test for the stability of each cultivar's response to the environment, as measured by the variance of that cultivar's statistical interaction effects with the environments.

Materials and Methods

Trees of 23 apple cultivars were propagated on Malling 9 (M.9) T337 rootstock by Adams County Nursery (Aspers, PA, USA) in 1993 (Table 1). 'Golden Delicious' was included in this evaluation to provide a standard commercial reference cultivar. The 1-year-old trees were dug in the fall of 1994 and planted at 28 sites located in the United States and Canada in spring 1995. Because of a shortage of trees of 'Senshu', only plantings designated for the "disease objective study" received this cultivar. Replicated quality data are therefore, not available for 'Senshu'. 'Pioneer Mac' was only included in "disease designated" plantings and also will not be discussed in this paper. Cooperators at 13 locations (Table 2), representing 14 planting sites (the West Virginia location provided fruit quality data from a "horticultural" planting and a "disease" planting), provided fruit quality data for the years 1997 through 2000. The experimental design was a randomized complete block with five blocks and a single tree of each cultivar per block. Because of a tree shortage among cultivars, some plantings were unbalanced with fewer than five replications. Filler trees, selected by the local cooperator, were used (to maintain the original experimental design) where trial cultivars were deficient. Trees were planted in north-south rows, when possible, at a spacing of 2.5 x 4.3 m. Details regarding the planting and cultural maintenance of the NE-183 plantings are presented by Crassweller et al. (10).

While some cultivars bore fruit in 1996, any fruit quality data collected for that year are not included in this paper. A standard protocol was developed for collecting objective fruit quality data. Beginning in 1997 and thereafter cooperators were instructed to harvest each cultivar when the average starch index (SI) rating fell within the range of 4 to 6 (considered optimum maturity) based on the Cornell Generic Starch-Iodine Index Chart (6). Data were collected on an individual tree basis. Total number of fruit harvested per tree was recorded along with total weight of harvested fruit. Quality variables were determined on a 10- fruit sample (hereafter referred to as "the sample") selected at random with the qualification that selected fruit would be "representative" of the cultivar and not exceptionally small or exceptionally large or unusually distorted fruit from the total lot of fruit harvested from each tree. When a cultivar had insufficient fruit for a quality evaluation from individual trees, fruit were combined from several or all trees to provide the necessary sample.

Mean fruit weight was determined by weighing the sample; the total length and diameter of the 10 fruits were recorded and mean fruit length, diameter and L/D ratio were

Table 1. Apple cultivars and selections and their parentage evaluated in the 1995 NE-183 "Multidisciplinary Evaluation of New Apple Cultivars" Regional Project[z].

Cultivar	Parentage
Arlet (Swiss Gourmet)	Golden Delicious x Idared
Braeburn	Chance seedling
Cameo (originally Carousel)	Chance seedling
Creston (originally BC8M15-10)	Golden Delicious x NJ381049
Enterprise	PRI 1661-2 x PRI 1661-1
Fortune (originally NY 429)	Red Spy x Empire
Fuji Red Sport #2	Sport of Fuji (Ralls Janet x Delicious)
Gala Supreme	Chance seedling
Ginger Gold	Chance seedling
Golden Delicious	Chance seedling
Golden Supreme	Chance seedling
GoldRush	Golden Delicious x Coop 17
Honeycrisp	Keepsake x ?
NY75414-1	Liberty x MacSpur
Orin	Golden Delicious x Indo
Pristine	Camuzat x PRI 1659-10
Sansa	Gala x Akane
Senshu	Toko x Fuji
Shizuka	Golden Delicious x Indo
Suncrisp (originally NJ 55)	Golden Delicious x NJ 303955
Sunrise	(McIntosh x Golden Delicious) x PCF-3-120
Yataka	Sport of Fuji
Pioneer Mac	Open pollinated seedling of McIntosh

[z] Photographs of apple cultivars available on NE-183 web site: www.ne183.org

calculated for the sample. Prior to destructive measurements, each fruit was subjectively rated for russeting using the following scale: 0 = no russet present, 1 = 0.1% to 5.0% of surface covered with russet, 2 = 5.1% to 10.0%, 3 = 10.1% to 15.0%, 4 = 15.1% to 20.0%, and 5 ≥ 20.1% of the surface russetted. In addition, the percent red surface overcolor typical for the cultivar was subjectively estimated to the nearest 5% for individual fruit and the mean reported for the sample. Mean flesh firmness was determined from two readings taken on the opposite sides of each fruit at the equator using a penetrometer fitted with an 11.1 mm tip. Firmness was reported as kilograms firmness. Soluble solids concentration was determined with a standard refractometer on a composite juice sample collected during flesh firmness measurements. Each fruit from the sample was cut in half through the equator and one of the halves dipped in a starch-iodine solution and visually rated after about one minute using the 8 point

Cornell University Generic Starch Chart (6). Average starch index (SI) for the sample was calculated. A 10 ml aliquot of juice was extracted from the fruit sample and added to sufficient distilled water and brought to a final volume of 100 ml. Titratable acidity was determined by titrating the diluted juice sample to pH 8.2 using 0.1 N NaOH. Results were reported as percent acidity as malic acid using the formula: % acid = ml NaOH x 0.067.

The objectives of the statistical analysis of each fruit quality attribute were to estimate and compare cultivar means across environments, where each location-year combination was an environment, and to test for the stability of each cultivar's responses across environments. In this approach, we treat the large array of environments occurring in our test as representative of the potential environments that could occur across the apple growing regions of the US and Canada. Our objective is not to determine performance in any particular environment, but to evaluate the cultivar's average level of response across all environments and the inconsistency of its response to the potential in each environment. The statistical analysis was accomplished using the MIXED procedure of SAS statistical software (Ver. 8 – Release 8.02; SAS Institute Inc., Cary, NC). The effects of cultivars were the fixed effects in the model. All other effects were random and included effects of locations, blocks nested in locations, years nested in locations, and trees nested in locations, blocks and cultivars. The final set of random effects was that for the interaction of cultivars and environments, and for these effects, the analysis fitted a separate variance component for each cultivar. This variance component for a cultivar measures the variation of its interaction effects across environments and will be referred to as the stability variance for that cultivar (30). A stable cultivar is one whose stability

Table 2. Locations and cooperators in the 1995 multidisciplinary apple cultivar evaluation trial coordinated by NE-183 who submitted fruit quality data for their trees.

Location		Cooperator	Planting Location
(BC)	British Columbia	Cheryl Hampson	Summerland, Canada
(MA)	Massachusetts	Duane W. Greene, Jon Clements	Belchertown
(ME)	Maine	Renae E. Moran	Monmouth
(NJ)	New Jersey	Winfred P. Cowgill, Robert D. Belding	Pittstown
(NYG)	New York	Susan K. Brown	Geneva
(NYH)	New York	James R. Schupp, Ed Stover	Highland
(NYI)	New York	Ian A. Merwin	Ithaca
(ONT)	Ontario	John A. Cline	Simcoe, Canada
(PAB)	Pennsylvania	George M. Greene II	Biglerville
(PAR)	Pennsylvania	Robert M. Crassweller	Rock Springs
(VT)	Vermont	M. Elena Garcia, Lorraine P. Burkett	Burlington
(WI)	Wisconsin	Teryl Roper	Sturgeon Bay
(WV)	West Virginia	Stephen S. Miller	Kearneysville

variance is zero, indicating that its interaction effects are all zero. This would mean that its mean in an environment differs from the mean of all cultivars in that environment by an amount that is the same for all environments. Thus a stable cultivar can be viewed as one whose mean responses for a population of environments parallel the means of the responses of all cultivars in those environments. In contrast, for an unstable cultivar, deviation from the mean in an apple growing environment is less accurately predicted by its mean deviation from the mean of all cultivar means.

The Satterthwaite option (Ver. 8 – Release 8.02; SAS Institute Inc., Cary, NC) was used for determining degrees of freedom. Cultivar generalized least squares means were compared using multiple t tests, each at the 5% significance level. Significance of a stability variance estimate was obtained by a one-tailed test based on a normal approximation and tests the hypothesis that the cultivar variance is equal to zero.

Results and Discussion

The mean SI rating at the time of harvest and the mean number of days deviation from the mean harvest date for 'Golden Delicious' for all cultivars from across the 14 planting sites for the years 1997 – 2000 are presented in Table 3. Cultivars harvested when the average SI rating indicated the fruit were well below target maturity (ie., mean SI $\leq$ 3.4) or above target maturity (mean SI $\geq$ 6.6) were deleted from the statistical analysis since fruit at these maturity levels were not considered representative of the cultivar. For a cultivar to be dropped from an individual site the average of all replicates at that site had to be outside the acceptable SI range. The cultivar 'Yataka' was found to be over-mature (Table 3, mean SI 7.4) when harvested at 13 of the 14 sites. Only two sites harvested 'Yataka' below the target value of SI 6.5: the BC site in three years and the PAB site in one year. Why a majority of sites were unable to harvest 'Yataka' in a mature condition is not clear, but it suggests that this cultivar may have unusually low starch values as it approaches maturity. Because only one site provided data representative of mature 'Yataka', the quality characteristics for this cultivar will not be described. The cultivar 'Sansa' was also deleted from the study due to a virus infection detected in the scion of all budded trees after planting. 'Fuji Red Sport No. 2' (hereafter referred to as 'Fuji') had the highest SI rating at the time of harvest and 'Ginger Gold' was harvested with the lowest SI rating (Table 3). Mean SI for all cultivars at the time of harvest was 5.0, which might be expected, and 'Golden Delicious', the reference standard, was harvested on average across all sites at SI 5.1. It may be largely accidental that a few cultivars like 'Fuji' were picked at a higher mean SI rating while others such as 'Ginger Gold' had a low mean SI at the time of harvest; however, this may in part reflect inherent differences in the rate of starch hydrolysis with some cultivars maintaining lower SI for a more prolonged period. It should also be noted that optimum maturity for different apple cultivars may occur at somewhat different SI ratings (24).

Among all sites reporting the SI rating and for all cultivars (within the acceptable range) the average SI rating was highest (SI = 5.5) at the PAB site and lowest (SI = 4.8) at the BC, MA, and PAR sites.

'Pristine' matured 58 days before the mean maturity date for 'Golden Delicious' (Table 3) and was the earliest maturing cultivar among the 19 cultivars evaluated. 'GoldRush', the latest maturing cultivar, matured a mean of 26 days after 'Golden Delicious'. Nine of the 19 cultivars matured before 'Golden Delicious' and six cultivars ('Creston', 'Fortune', 'NY 75414-1', 'Orin', 'Shizuka', and 'Yataka') matured within one week of 'Golden Delicious' (Table 3).

Fruit weight and size: The mean fruit weight, diameter, length, and length/diameter (L/D) ratio for the 19 apple cultivars, averaged across all 14 planting sites, are presented in Table 4. Based on the 10-apple sample selected for quality measurements 'Fortune' and 'Shizuka' produced the largest apples. Though significantly smaller than the largest fruit, 'Enterprise' and 'Honeycrisp' also had fruit weight above 240 g per fruit and could be considered large to very large. Greene (15) reported similar

Table 3. Mean starch index (SI) rating at the time of harvest for 19 apple cultivars on Malling 9 T337 rootstock and number of days deviation from mean harvest date for 'Golden Delicious' from across 14 planting sites in North America in the NE-183 Apple Cultivar Evaluation Project for the years 1997 through 2000[z].

Cultivar	SI rating	Days deviation from Golden Del.
Arlet	5.5 ab[y]	-24
Braeburn	5.1 cde	+19
Cameo	4.9 efgh	+12
Creston	5.3 abcde	-6
Enterprise	5.1 def	+15
Fortune	4.7ghi	+5
Fuji Red Sport No. 2	5.6 a	+8
Gala Supreme	4.6 hi	+18
Ginger Gold	4.3 i	-36
Golden Delicious	5.1 def	0
Golden Supreme	4.9 efgh	-21
GoldRush	4.7 fghi	+26
Honeycrisp	5.5 abc	-22
NY 75414-1	4.7 hi	-5
Orin	5.1 cde	+7
Pristine	5.4 abcd	-58
Shizuka	5.2 bcde	+1
Suncrisp	5.1 defg	+11
Sunrise	4.7 hi	-47
Yataka	7.4[w]	-2
Mean for all cultivars	5.0	-5

[z] Average SI rating for harvested fruit from all replicate trees within a site determined to fall within the range 3.5 to 6.5; SI 1 = fully immature, SI 8 = fully over-mature.
[y] Means followed by a common letter are not significiantly different by a t test at the 5% significance level.
[x] Calculated from mean harvest date for each cultivar across all sites; - indicates days before 'Golden Delicious' and + indicates days after 'Golden Delicious'.
[w] Mean SI fell outside the acceptable range; not included in the overall cultivar average.

findings for 'Fortune', 'Shizuka', and 'Honeycrisp' grown in Massachusetts. He also characterized 'Enterprise' as a "medium to large" apple, but did not provide fruit weight data for this cultivar. Weis et al. (35) reported an average fruit weight for 'Shizuka' of 266 g when harvested over a four-year period in Massachusetts. Norton et al. (28) reported that 'Shizuka' and 'Honeycrisp' were the largest fruits among 50 cultivars evaluated from fifth-leaf trees at Prosser, WA; fruits averaged 373 g for these two cultivars at this planting site. In our study, 'Pristine' produced the smallest fruit. Mean

fruit weight across all cultivars and sites was 219 g per fruit. Among the 14 sites reporting fruit weight (data for individual sites not shown), fruit grown at the BC location had the largest average fruit weight among all 19 cultivars evaluated, 295 g per fruit. In contrast, the PA locations (Biglerville and Rock Springs) had the lowest mean fruit weight (189 g) when averaged over all 19 cultivars. Mean fruit weights determined for four cultivars in this study differed from the descriptions provided in The Brooks and Olmo Register of Fruit and Nut Varieties (19): 'Arlet' (also known as 'Swiss Gourmet') and 'Orin' are described as medium to large with 'Orin' as 250 to 300 g and 'Sunrise' as "large, mostly over 200 g" while 'Honeycrisp' is characterized as medium. In our study, 'Sunrise' and 'Arlet' were among the smallest fruit, averaging less than 190 g and 'Orin' was less than 200 g while 'Honeycrisp' was one of the largest apples at 248 g per fruit. Evaluations at three locations in Washington State (28) reported average fruit weights for 'Sunrise' and 'Arlet' above 245 g at one site but below 194 g for 'Sunrise' at a second site and about 220 g per fruit for 'Arlet' at a third site. Fruit weights reported here for the samples agree closely with the fruit weights reported for the whole-tree samples by Crassweller et al. (10). Crop load values for the various cultivars may also be found in Crassweller et al. (10).

When a stability variance analysis was performed on the fruit weight data (Table 4) 'Arlet', 'Fuji', 'Gala Supreme', 'Ginger Gold', and 'Orin' were found to be stable cultivars for fruit weight. A stability variance of "0" for 'Orin' indicates this cultivar is perfectly stable and, therefore, will produce fruit that are smaller than the mean for all cultivars grown in a given environment, regardless of whether it is a good or poor growing environment. In our study mean fruit weight for 'Orin' was 25 g less than the mean for all cultivars (Table 4). Therefore, when 'Orin' is grown at a different site among the group of cultivars evaluated in this study one can expect it to produce fruit weighing 25 g less than the mean for all the cultivars at that site. Fourteen of the 19 cultivars evaluated, including the largest cultivars ('Fortune', 'Shizuka', 'Enterprise' and 'Honeycrisp') lacked the stability in mean fruit weight that the data indicated for 'Orin' and the other stable cultivars. Stability variance, therefore, indicates that for these cultivars fruit weight response is very unpredictable. To illustrate the effect of this response in our study, mean 'Fortune' fruit weight, which was 81 g greater than the overall cultivar mean (219 g), but as an unstable cultivar its mean weight at other apple sites may differ from the site mean by substantially more or less than 81 g. However, with a standard deviation (SD) of 26.5 g (square root of the stability variance of 703) it is not likely that the fruit weight of 'Fortune' will be less than the mean of all cultivars. In contrast, 'Honeycrisp', which had a fruit weight 29 g greater than the overall mean, and with a SD of 31.2 ($\sqrt{}$ of 976), may have a fruit weight much larger, slightly larger, or slightly smaller than the mean for all cultivars.

Fruit diameter was significantly larger for 'Fortune' than all other cultivars evaluated (Table 4). Five additional cultivars had mean fruit diameters of 8.0 cm or greater including 'Shizuka', 'Enterprise', 'Honeycrisp', 'Gala Supreme', and 'Ginger Gold'. Bultitude (8) defined fruit size of 7.5 to 8.4 cm as large and fruit 8.5 cm or more as very large. The breeders of 'Fortune' characterized the apple as large to very large (7) and the findings in this study would support their description. Mean fruit diameter for all 19 cultivars was 7.9 cm. In these evaluations, 'Honeycrisp' fruit diameter was much greater than the diameter (6.0 to 7.0 cm) characterized for this cultivar (19). 'Pristine' and 'Arlet' had the smallest mean fruit diameters. Fruits of this diameter have been defined as medium large (8). Janick et al. (23) reported average fruit diameters of 64 to 70 mm for 'Pristine', but indicated that fruit as large as 80 mm could be produced in some growing locations. The Brooks and Olmo Register of Fruit and Nut Varieties (19) describes 'Arlet' as a medium to large fruit and the findings in this study would agree. Based on stability variance analysis for fruit diameter, eight cultivars were highly stable, but none were found to be perfectly stable. Only 'Enterprise', 'Gala Supreme', and 'Ginger Gold' may be predicted to produce fruit with a diameter greater than the mean fruit diameter for all

cultivars, while 'Arlet', 'Braeburn', 'Golden Delicious', and 'Orin' may be expected to produce fruit of a lesser diameter than the mean diameter. Eleven cultivars differed significantly from a zero stability variance in fruit diameter indicating that their performance is unpredictable when grown in a different environment.

Fruit of 'Shizuka' were the longest with a mean fruit length significantly greater than the other 18 cultivars evaluated (Table 4). Fruit length for 'Pristine' was significantly less than all other cultivars. 'NY 75414-1' and 'Arlet' also exhibited somewhat lower fruit lengths suggesting these fruit could be characterized as oblate or flattened as opposed to oblong or conic (4). Mean fruit length over all 14 planting sites and 19 cultivars was 7.0 cm. 'Orin' and 'Gala Supreme' were perfectly stable with regard to fruit length. Six additional cultivars exhibited stability in fruit length while 11 of the 19 cultivars were unstable (Table 4).

While fruit length may be related to fruit shape or form, the L/D ratio is a better indicator of fruit shape. The highest mean L/D was 0.93 recorded for six different cultivars: 'Creston', 'Golden Delicious', 'Golden Supreme', 'GoldRush' 'Orin', and 'Shizuka' (Table 4). 'Golden Delicious' is typically characterized as a round-conic (8) or conic (26) apple. Based on our field observations an L/D ratio of 0.93 would support the "round-conic" description given

Table 4. Mean fruit weight, size, length/diameter (L/D) ratio, and corresponding stability variances for 19 apple cultivars evaluated over 14 planting sites in North America in the 1995 NE-183 Multidisciplinary Apple Cultivar Evaluation Regional Project for the years 1997 through 2000.

	Fruit weight (g)		Fruit diameter (cm)		Fruit length (cm)		L/D ratio	
Cultivar	Mean[z]	Stability variance	Mean	Stability variance	Mean	Stability variance	Mean	Stability variance
Arlet	177 i	114	7.2 j	0.01	6.6 gh	0.11*	0.91 bcd	0.0007*
Braeburn	210 ef	248*[y]	7.6 h	0.02	6.9 de	0.02	0.90 cdef	0.0003
Creston	228 d	389*	7.9 defg	0.24*	7.4 c	0.14*	0.93 a	0.0003
Cameo	210 ef	344*	7.8 efg	0.07*	7.0 de	0.07*	0.90 ef	0.0
Enterprise	262 b	234*	8.5 b	0.03	7.6 b	0.03	0.89 ef	0.0003
Fortune	300 a	703*	9.1 a	0.08*	7.7 b	0.03	0.85 h	0.0001
Fuji Red Sport No. 2	222 d	38	7.9 def	0.01	6.9 def	0.01	0.87 g	0.0001
Gala Supreme	234 cd	342	8.2 c	0.07	6.8 ef	0.0	0.83 i	0.0002
Ginger Gold	232 cd	300	8.0 d	0.04	7.3 c	0.10	0.92 abcde	0.0023*
Golden Delicious	205 f	204*	7.7 gh	0.02	7.1 c	0.11*	0.93 ab	0.0008*
Golden Supreme	221 de	397*	7.7 fgh	0.05*	7.2 c	0.05*	0.93 a	0.0003*
GoldRush	191 gh	286*	7.4 i	0.04*	6.9 def	0.06*	0.93 a	0.0
Honeycrisp	248 bc	976*	8.3 c	0.16*	7.3 c	0.16*	0.88 fgh	0.0037*
NY 75414-1	179 i	289*	7.9 def	0.11*	6.5 h	0.11*	0.82 i	0.0005*
Orin	194 g	0	7.5 i	0.01	6.9 d	0.0	0.93 a	0.0
Pristine	136 j	536*	7.1 j	0.15*	5.9 i	0.08*	0.83 i	0.0001
Shizuka	295 a	895*	8.6 b	0.08*	8.0 a	0.08	0.93 a	0.0
Suncrisp	227 d	553*	7.9 de	0.10*	7.3 c	0.26*	0.92 abc	0.0037*
Sunrise	184 hi	142*	7.5 i	0.09*	6.7 fg	0.05*	0.90 def	0.0003*
Mean all cultivars	219	–	7.9	–	7.0	–	0.89	–

[z] Mean of 11 locations in the United States and 2 locations in Canada; means sharing a common letter are not significantly different by a t test at the 5% significance level.

[y] * = significantly different from 0 by a one-sided z test at the 5% significance level.

for 'Golden Delicious' as well as the other cultivars with an L/D ratio of 0.93. 'Gala Supreme', 'NY 75414-1', and 'Pristine' had the lowest L/D ratios among the cultivars evaluated and could be most appropriately characterized as oblate. L/D ratios determined in this study agree closely with those reported by the breeders for 'Enterprise' (11), 'GoldRush' (12), and 'Pristine' (23). In this study fruit shape for 'Suncrisp' was more conic than described by Goffreda et al. (13). Fruit length and diameter were recorded at all sites and L/D ratio computed (data not shown). When averaged over all cultivars, the BC site produced fruit with highest L/D ratio (0.95) followed by NYI (0.94), ON (0.93), and ME (0.93). The lowest L/D ratio (0.88) averaged across all cultivars occurred at the WV sites. The WV plantings were located at the most southern latitude among the 13 locations in this study while the BC site was the most northern latitude site. Temperatures during early fruit development affect fruit shape and high temperatures during this period are known to reduce fruit elongation (32). Data from our study with 19 apple cultivars would support the contention that fruit elongation and L/D ratio will likely be lower in the more southern and warmer growing regions. Four cultivars were found to be perfectly stable with regard to L/D ratio: 'Cameo', 'GoldRush', 'Orin' and 'Shizuka'. In terms of fruit weight, size and L/D ratio, and based on stability variance analysis, 'Fuji' and 'Orin' were consistently stable cultivars among those evaluated while 'Honeycrisp' was consistently unstable for these variables.

Flesh quality: Mean flesh firmness, SSC, and TA for the 19 cultivars across the 13 planting sites (flesh firmness was not reported for the PAR site) are presented in Table 5. 'Braeburn' and 'GoldRush' had the highest flesh firmness at harvest averaging 9.1 kg force or greater over four seasons. Five cultivars had mean flesh firmness values between 8.2 and 9.0 kg at harvest: 'Arlet', 'Fuji', 'Gala Supreme', 'Golden Supreme', and 'Suncrisp'. It should be noted that 'Arlet' and 'Fuji' displayed such high flesh firmness even though they were the most mature cultivars at harvest as indicated by SI (Table 3). 'NY 75414-1' had the lowest flesh firmness at harvest (Table 5), even though it was harvested at a rather low mean SI (Table 3). The overall mean flesh firmness was 7.8 kg at harvest (Table 5). The PAB site reported the highest flesh firmness among the sites averaged over all cultivars (data not shown). This may be a result of the smaller fruit size at the PAB location. Stability analysis of the flesh firmness data indicated four stable cultivars: 'Creston', 'Enterprise', 'Orin', and 'Shizuka'. Fifteen cultivars were unstable with regard to flesh firmness.

SSC for the 19 cultivars ranged from a low of 12.3% for 'Pristine' to a high of 15.6% for 'Gala Supreme' (Table 5). 'GoldRush' and 'Sunrise' were not significantly different from 'Gala Supreme' and 'Pristine', respectively. Ten cultivars had a mean SSC above the overall mean of 13.9%. Only three cultivars, 'Creston', 'Enterprise', and 'Ginger Gold' were stable for the SSC variable. Mean SSC among all cultivars was highest at the NYH site (15.0 %) and lowest at the VT location (13.4 %).

Among the 19 cultivars in this study 'GoldRush' and 'Pristine' had the highest TA while 'Fuji' and 'Orin' had the lowest TA. A total of 10 cultivars had TA at or above the overall cultivar mean TA of 0.65% malic acid. 'GoldRush' is characterized as "sprightly acid" (12), but 'Pristine' is described as "mild acid to sweet" (23). Greene and Weis (18) characterized 'Pristine' as "quite acidic, with little perceptible sugar." 'Fuji' and 'Orin', apples of Japanese origin are characterized as sweet, low acid fruit (19). It is of interest to note that 'Honeycrisp', described as a "well-balanced, sweet/tart" apple (5), had a relatively high TA (0.76% malic acid). Two cultivars, 'Fuji' and 'Sunrise', were perfectly stable for TA (Table 5). Nine other cultivars were stable for the TA variable.

Red color and russet: All of the locations in this study, except the WV site, were located in the more northern growing regions of North America where good red overcolor may be expected. 'Enterprise' and 'NY 75414-1' had the highest amount of red color at 85 % or greater of the fruit surface (Table 6). For 'Enterprise' this level of overcolor

Table 5. Mean fruit flesh firmness, soluble solids concentration, titratable acidity and corresponding stability variances for 19 apple cultivars evaluated over 14 planting sites in North America in the 1995 NE-183 Apple Cultivar Evaluation Regional Project for the years 1997 through 2000.

	Flesh firmness (kg)		Soluble solids concentration (%)		Titratable acidity[z]	
Cultivar	Mean[y]	Stability variance	Mean	Stability variance	Mean	Stability variance
Arlet	8.7 b	1.1*[x]	14.0 def	0.5*	0.70 cd	0.0069
Braeburn	9.1 a	1.6*	13.3 ijk	0.6*	0.72 bcd	0.0142*
Creston	7.4 ghi	0.5	13.6 ghij	0.2	0.56 gh	0.0005
Cameo	8.0 e	1.2*	14.1 defg	1.1*	0.59 gh	0.0001
Enterprise	7.8 f	0.2	14.5 c	0.2	0.71 cd	0.0061*
Fortune	7.2 hi	2.1*	13.8 fghi	0.6*	0.71 bcd	0.0008*
Fuji Red Sport No. 2	8.2 cde	0.9*	14.4 cd	0.7*	0.44 j	0
Gala Supreme	8.4 bcd	1.7*	15.6 a	1.5*	0.65 de	0.0027
Ginger Gold	7.8 efg	1.5*	13.0 k	0.2	0.52 fghij	0.0046
Golden Delicious	7.5 fgh	1.9*	15.1 ab	1.1*	0.61 efg	0.0037
Golden Supreme	8.4 bc	1.5*	13.4 hijk	0.8*	0.50 i	0.0027
GoldRush	9.4 a	2.0*	15.5 a	2.9*	0.98 a	0.0549*
Honeycrisp	7.5 fgh	1.1*	13.2 jk	0.5*	0.76 bc	0.0114*
NY 75414-1	6.1 k	0.7*	13.9 efg	0.3*	0.78 b	0.0052*
Orin	8.1 de	0.2	14.2 cde	0.4*	0.39 j	0.0139
Pristine	6.6 j	0.9*	12.3 l	0.8*	0.87 a	0.0157*
Shizuka	7.2 i	0.5	14.0 defgh	1.3*	0.54 hi	0.0007
Suncrisp	8.2 cde	2.9*	14.6 bc	1.4*	0.77 bc	0.0147*
Sunrise	6.7 j	2.0*	12.5 l	0.6*	0.63 ef	0
Mean, all cultivars	7.8	–	13.9	–	0.65	–

[z] titratable acidity expressed as % malic acid.

[y] Mean of 11 locations in the United States and 2 locations in Canada; means sharing a common letter are not significantly different by a t test at the 5% significance level.

[x] * = significantly different from 0 by a one-sided z test at the 5% significance level.

compares favorably with the level (95 %) expected by the breeders (11). Among the red skin cultivars 'Creston' produced the least amount of red overcolor. Greene (15) reported earlier that 'Creston' lacked good red color development even under conditions in Massachusetts. 'Sunrise' produced very good red color despite maturing in August, but for 'Honeycrisp' mean red overcolor was somewhat disappointing at less than 50%. The mean red overcolor among the 11 red skin cultivars in this study was 63 % surface red color. All the yellow skin cultivars and the green 'Orin' developed some degree of red or reddish/ orange blush. Among the yellow skin

Table 6. Mean red overcolor, surface russet, and corresponding stability variances for 19 apple cultivars evaluated over 14 planting sites in North America in the 1995 NE-183 Apple Cultivar Evaluation Project for the years 1997 through 2000.

	Red overcolor (%)[z]		Russet rating[y]	
Cultivar	Mean[x]	Stability variance	Mean	Stability variance
Arlet	55 ef	263*[w]	2.8 a	1.69*
Braeburn	69 bc	246*	0.4 e	0.02
Creston	33 g	260*	1.2 cd	0.93*
Cameo	56 def	305*	0.5 de	0.17*
Enterprise	88 a	19	0.3 ef	0
Fortune	73 b	334*	0.4 ef	0.05
Fuji Red Sport No. 2	64 bcde	110*	1.1 c	0.61*
Gala Supreme	65 bcd	138*	2.3 ab	2.20*
Ginger Gold	6 j	36	0.9 c	0
Golden Delicious	8 ij	40*	1.3 c	0.54*
Golden Supreme	12 hi	31*	1.1 c	0.45*
GoldRush	15 h	29	1.0 c	0.31*
Honeycrisp	47 f	276*	0.9 c	0.13*
NY 75414-1	85 a	145*	0.9 cd	0.43*
Orin	9 ij	56*	1.2 c	0.28*
Pristine	8 ij	36	0.9 c	0.06
Shizuka	7 j	12	1.2 c	0.82*
Suncrisp	28 g	52*	1.5 bc	1.60*
Sunrise	62 cde	203*	0.2 f	0.04
Mean, all cultivars	42	——	1.1	——
red cultivars	63	——	——	——
yellow/green cultivars	11	——	——	——

[z] Visual rating to the nearest 5% surface red color to include blush on yellow skin cultivars.

[y] Rating is percent surface covered with russet: 0 = no russet present, 1 = 0.1% to 5.0%, 2 = 5.1% to 10.0%, 3 = 10.1% to 15.0%, 4 = 15.1% to 20.0%, and 5 = over 20%

[x] Mean of 11 locations in the United States and 2 locations in Canada; means sharing a common letter are not significantly different by a t test at the 5% significance level.

[w] * = significantly different from 0 by a one-sided z test at the 5% significance level.

cultivars 'Suncrisp' produced the greatest amount of red overcolor at 28 %. In describing 'Suncrisp' (NJ55) Goffreda et al. (13) indicated this cultivar could have up to 40% orange-red blush covering the fruit surface at harvest. 'Pristine' and 'Ginger Gold', also yellow skin cultivars that mature in mid- to late summer, exhibited some degree of red blush. 'GoldRush', reported to develop a heavy blush on sun-exposed fruit (12), had a mean of 15 % surface red overcolor. Mean red overcolor (blush) among the eight yellow/green skin cultivars was 11 %. Five cultivars exhibited stability in red overcolor, but only one of these cultivars, 'Enterprise' was a red skin cultivar (Table 6).

Some cultivars (such as 'Golden Delicious') are prone to russet formation on the skin, which detracts from appearance. This physiological disorder tends to occur with greater frequency in more humid growing regions such as the eastern United States. Five locations did not report russet rating: MA, ME, NYG, NYI, and PAR. Among the remaining nine planting sites reporting russet, 'Arlet' and 'Gala Supreme' had the most russet (Table 6). Description found in The Brooks and Olmo Register of Fruit and Nut varieties (19) indicates that 'Arlet' may have "occasional russet", however, Greene and Weis (18) indicated 'Arlet' had a tendency to produce russet that may affect 25% of the surface. Norton et al. (28) discarded 'Arlet' from further testing at their western Washington (USA) site because of russet, but indicated that in a more arid climate (eastern Washington) this cultivar had little tendency for russet. The russet rating for 'Suncrisp' was significantly less than for 'Arlet', but not 'Gala Supreme'. Goffreda et al. (13) indicated that 'Suncrisp' was more prone to russet than 'Golden Delicious'; however, in the present trials there was no difference between these two cultivars. 'Sunrise' had the lowest russet rating followed closely by 'Enterprise' and 'Fortune'. Mean russet rating over all cultivars was 1.1 indicating that most cultivars exhibited less than 5 % surface russet. Twelve cultivars rated at or below the mean russet rating. Among the nine sites reporting russet ratings (data not shown), NJ had the highest mean russet rating (2.0) and BC had the lowest mean russet rating (0.6). Stability variance analysis indicated that two cultivars were perfectly stable relative to russet rating, 'Enterprise' and 'Ginger Gold'. 'Braeburn', 'Fortune', 'Pristine' and 'Sunrise' were also stable cultivars for russet while 13 cultivars were unstable.

Conclusions

Among the 19 cultivars evaluated in this study, no one cultivar stood out as superior in all fruit quality variables measured when averaged across all locations. Several cultivars exhibited large fruit size, including 'Enterprise', 'Fortune', 'Honeycrisp', and 'Shizuka'. However, stability analysis indicated that these cultivars were unstable for fruit weight and fruit diameter except 'Enterprise' which had a stable fruit diameter. 'GoldRush', a scab resistant cultivar, had superior fruit firmness and SSC at harvest, but also had the highest TA and likely would benefit from a period of storage for best flavor as suggested by Greene (15); 'GoldRush' was unstable for all three of these variables. Combining a high level of red overcolor and a low amount of russet, 'Enterprise' stood out among the cultivars evaluated for appearance. 'Honeycrisp', which has recently received much attention by growers and consumers (25), performed well, but was unstable for all quality attributes measured. Among the 19 cultivars evaluated, 'Enterprise' and 'Ginger Gold' were found to be stable for seven of the nine variables measured while 'Honeycrisp', 'NY 75414-1', and 'Suncrisp' were consistently unstable. Except for a lack of flesh firmness and some appearance of russet, 'Shizuka' performed well and was generally stable, although fruit size may be problematic in some locations given its instability in this variable.

Literature Cited

1. Anonymous. 1995. Apple's appearance, inertia and crunch influence purchase. Great Lakes Fruit Grower News 34(3):54-55.
2. Ballard, J. 1995. Testing new apple varieties is a never-ending project. Proc. 91st Wash State Hort. Assoc. 91:145-147.
3. Barritt, B.H. 2003. The apple world 2003 – present situation and developments for producers and consumers. Compact Fruit Tree 36:15-18.
4. Beach, S.A. 1905. The apples of New York, Vol. I. J.B. Lyon Co., Albany, New York.
5. Bedford, D. 2001. Honeycrisp. Compact Fruit Tree 34:98-99.
6. Blanpied, G.D. and K.J. Silsby. 1992. Predicting harvest date windows for apples. Cornell Coop. Ext. Publ. Info. Bul. 221.
7. Brown, S.K., R.D. Way, D.E. Terry, and K.G. Livermore. 1995. 'Fortune' apple. N.Y. Agric. Expt. Sta. Food Life Sci. Bul. 147.
8. Bultitude, J. 1983. Apples: a guide to the identification of international varieties. Univ. of Washington Press, Seattle, Washington.
9. Conceição de Oliveira, M., R. Sichieri, and A. Sanchez Moura. 2003. Weight loss associated with daily intake of three apples or three pears among overweight women. Nutrition 19:253-256.
10. Crassweller, R.W., R. McNew, A. Azarenko, B. Barritt, R. Belding, L. Berkett, J. Cline, W. Cowgill, D. Ferree, E. Garcia, D. Greene, G. Greene, C. Hampson, I. Merwin, D. Miller, S. Miller, R. Moran, M. Parker, D. Rosenberger, C. Rom, T. Roper, J. Schupp, and E. Stover. 2004. Five year summary of the NE-183 apple cultivar trial – growth and yield characteristics. J. Amer. Pomol. Soc. 58: (in press).
11. Crosby, J.A., J. Janick, P.C. Pecknold, J.C. Goffreda, and S.S. Korban. 1994a. 'Enterprise' apple. HortScience 29:825-826.
12. Crosby, J.A., J. Janick, P.C. Pecknold, J.C. Goffreda, and S.S. Korban. 1994b. 'GoldRush' apple. HortScience 29:827-828.
13. Goffreda, J.C., A. Voordeckers, and S.A. Mehlenbacher. 1995. 'NJ55' apple. HortScience 30:387-388.
14. Goldman, I.L. 2003. Recognition of fruit and vegetables as healthful:vitamins and phytonutrients. HortTechnology 13:252-258.
15. Greene, D.W. 1998. Promising high quality apples evaluated in New England. Fruit Var. J. 52:190-199.
16. Greene, D.W. 2004. Multidisciplinary evaluation of new apple cultivars: the NE-183 regional project. J. Amer. Pomol. Soc. 58: 61-64.
17. Greene, D.W. and W.R. Autio. 1990. Evaluation of ripening and fruit quality of 'Gala' and 'McIntosh' apples at harvest and following air storage. Fruit Var. J. 44:117-123.
18. Greene, D.W. and S.A. Weis. 2003. Apple varieties with a future. Compact Fruit Tree 36:55-56.
19. Greene, D.W., R.A. Norton, C.R. Rom, R.L. Stebbins, and R. Way. 1997. The Brooks and Olmo Register of Fruit and Nut Varieties. Third Edition. ASHS Press. Alexandria, VA.
20. Hampson, C.R., H.A. Quamme, J.W. Hall, R.A. MacDonald, M.C. King and M.A. Cliff. 2000. Sensory evaluation as a selection tool in apple breeding. Euphytica 111:79-90.
21. Harker, R. 2002a. Improve fruit quality to increase demand. Good Fruit Grower 53(3):27.
22. Harker, R. 2002b. Consumers like apples for health, taste, texture. Part 4: Beliefs, attitudes, and perceptions. Good Fruit Grower 53(6):16-17.
23. Janick, J., J.A. Crosby, P.C. Pecknold, J.C. Goffreda, and S.S. Korban. 1995. 'Co-op 32' (Pristine™) apple. HortScience 30:1312-1313.
24. Knee, M., S.G.S. Hatfield, and S.M. Smith. 1989. Evaluation of various indicators of maturity for harvest of apple fruit intended for long-term storage. J. Hort. Sci. 64:403-411.
25. Lynd, M. 2001. Honeycrisp is a "killer" apple. Compact Fruit Tree 34:114.
26. Manhart, W. 1995. Apples for the twenty-first century. North American Tree Company, Portland, OR.
27. Miller, S.S. 1991. Apple cultivars – current situation and trends around the world: An introduction. Fruit Var. J. 45:75-76.
28. Norton, R.A., G.A. Moulton, J. King, and D. Ophardt. 1993. Apple cultivar trials – 1992. Tree Fruit Res. Commission, Wash. State Univ., Pullman, WA.
29. O'Rourke, D. 2003. Changing dynamics of world fruit markets. Compact Fruit Tree 36:12-14.
30. Piepho, H.P. 1999. Stability analysis using the SAS system. Agronomy J. 91:154-160.
31. Ricks, D., K. Heinze, and J. Beggs. 1995. Consumer preference information related to Michigan apples. Great Lakes Fruit Grower News 34(10):38-39.
32. Shaw, J.K. 1914. A study of variations in apples. Mass. Agr. Expt. Sta. Bul 149. p. 29-36.
33. Stebbins, R.L., A.A. Duncan, O.C. Compton, and D. Duncan. 1991. Taste ratings of new apple cultivars. Fruit Var. J. 45:37-44.
34. von Alvensleben, R. and T. Meier. 1990. The influence of origin and variety on consumer perception. Acta Hort. 259:151-161.
35. Weis, S.A., D.W. Greene, and W.J. Bramlage. 2002. Comparing the harvest and storage characteristics of Mutsu and Shizuka apples. Univ. Mass. Fruit Notes 67(3):1-4.
36. Wolfe, K., X. Wu, and R.H. Liu. 2003. Antioxidant activity of apple peels. J. Agric. Food Chem. 51:609-614.